Integrating Human Factors Knowledge Into Certification: The Point of View of the International Civil Aviation Organization (ICAO)

Daniel Maurino & Vincent Galotti

International Civil Aviation Organization

Introduction

Human factors has matured into a core technology. This contention is best reflected in the attention the aviation industry has dedicated to this technology over the last decade. The aviation industry is going through what has been dubbed "the golden era" of aviation human factors, both in research as well as in application, through human factors training for operational personnel, human factors consideration in accident prevention, and investigation and in workstation design. Although skeptics and critics still exist in all segments of the international community who would state otherwise, the contribution of human factors study and application to aviation system safety and effectiveness remains beyond question.

The most important step, however, has yet to be taken. No matter how potentially applicable the research, no matter how performance-enhancing the training, no matter how sensible the investigation of accidents and, finally, no matter how much the ergonomic know-how is incorporated into workstation design, all of these advances can be deemed to be remedial measures. From the perspective of advanced technology systems safety, the major contribution of human factors will be fully realized only after the huge amount of existing and available human factors knowledge is translated into the certification process of such systems; that is, before the system is in operation. The incorporation of human factors requirements into the certification of new, advanced technology remains to be the challenge of the decade.

It has repeatedly been suggested that, unless awareness about a problem is first gained, for practical purposes, that problem does not exist. Therefore, this paper advances a justification of why human factors requirements should be given the same consideration and weight as traditional "hard core" requirements that exist during the certification process of equipment, procedures and personnel that make up advanced aviation systems. Such justification is considered vital to secure the understanding and the necessary commitment of designers as well as regulators involved in certification processes. Secondly, an approach to the inclusion of human factors certification requirements is proposed, based on existing ICAO regulatory requirements and guidance material. An understanding of the role of ICAO in the processes of regulation is therefore necessary for the reader to identify how its mechanisms may be useful in attaining the required goals of human factors certification of advanced systems through such mechanisms.

Human Factors Certification of Advanced Aviation Technologies
Edited by J. A. Wise, V. D. Hopkin, and D. J. Garland

Although general in nature, such a proposal is viewed as one feasible way to make inroads toward the stated goal of human factors certification of advanced aviation systems.

The consideration of human factors certification requirements during the design stage of advanced, new technology systems may be seen as resting over a three-legged stool. The first leg, the equipment that a system will utilize to achieve its goals, has traditionally attracted ergonomic considerations associated with equipment design, usually centred around "knobs and dials." As of lately, this view has expanded to include the so-called other important aspect of human factor's study which deals with the cognitive, behaviourial and social processes of the human operators. Study on this area must be furthered. The second leg of the stool, the procedures required to operate the equipment, however, has been largely unaddressed. Procedures are not inherent to equipment, but must be developed. The importance of proper human factor's consideration in the design of procedures can not be overstated. Lastly, the third leg of the stool, certification of personnel who will operate the equipment, is very much underway but far from being complete.

Background

Over time, the contribution of the human factors profession toward advancing the safety and effectiveness of socio-technical systems, including aviation, has been hindered because of its piecemeal approach. Designers, engineers, trainers and regulators have historically favoured solutions which were biased by their professional backgrounds. This often resulted in a state of affairs which, although the individual components had been designed to the maximum level of available know-how and expertise, the aviation system as a whole received only marginal benefits from the technological progress. Furthermore, an unlimited trust in technology-driven approaches toward system development often overlooked the fact that the human component of the system still remains as the old "Mark I" version with basically the same limitations as existed 5,000 years ago. Indeed, the shortcomings of overeliance on technology to overcome system safety deficiencies have clearly been identified by research, as well as by the investigation of major socio-technical systems' catastrophes. However, rather than revising the wisdom of this approach, some would suggest that industry has renewed its commitment to technology with a blind euphoria over technical systems claimed to be "absolutely safe." One can not help but reflect on the "Titanic syndrome": "such marvelous technology could not possibly sink." History, however, suggests otherwise.

When pursuing safety and effectiveness in aviation, we have tended to think in individual rather than in collective terms. At the operational level, this is reflected by the pervasiveness of remedial actions addressed to individuals rather than to the system as a whole. A good example of this assertion is the omnipresence of the *pilot error* clause in accident investigation literature, which would seem to be a relic from World War II. Even with the introduction of human factors into existing protocols for accident investigation, the focus still often remains on those at the tip of the arrow. It is a common mistake to narrow down an investigation of human factors in accidents and incidents to the behaviourial and cognitive aspects as they relate to the performance of operational personnel involved in the actual occurrence. Such investigations should rather broaden their perspective to include overall system performance, including the behaviourial and cognitive elements of all of its human components and not just those at the tip of the arrow.

From the perspective of design, the picture does not vary substantially. Technology has been introduced piecemeal, producing excellent examples of equipment which is quite remarkable. However, because of the lack of appropriate macro-analysis at the time that individual technical designs are introduced into a system, the interface with other system components including, first and foremost, the human, are sometimes rather clumsily accomplished. This less than optimum interface has demanded, often times, significant adaptation efforts to accommodate a new piece of equipment into a system already in operation. Such adaptation often involves trade-offs and compromises which, at the end of the day, diminish the benefits of the new design in terms of its contribution to safety and effectiveness.

The introduction of high-level automation into flight decks and air traffic control units stand as good examples of the shortcomings discussed in the previous paragraph. Some would consider it naive to accept that the design and introduction of automation routinely progresses beyond the level of micro-design and micro-analysis. The consequences are well documented and the equipment intended to reduce human error has in many cases merely displaced it. Likewise, designs intended to alleviate workload often increase it at the most inappropriate times and reduce it during times where it may actually foster boredom and complacency. The absence of macro-ergonomic considerations has led many to contend that the introduction of automation into many advanced aviation systems (e.g., new flight deck design, advanced automated ATC systems, intelligent reasoning tools, etc.) reflects a regrettable, although quite preventable, failure of the human factors profession. The good news is that lessons have been learned, and these lessons will hopefully be translated into the design of the future global ICAO Communications, Navigation, Surveillance/Air Traffic Management (CNS/ATM) System. This system is briefly described in a later chapter of this paper because of its importance to the future of aviation and the criticality of addressing human factors certification concerns at an early stage in its development.

ICAO's Role in Regulation and Implications for Certification

Regulation remains the vehicle to ensure that the hard learned lessons do not vanish into the labyrinths of sectorial interests or into the fragility of human memory. The literature being produced on how to proceed in securing safety and effectiveness in new technological systems accumulates rapidly. The justification behind these new approaches is well-documented and beyond challenge. Seldom a week goes by without one major human factors event taking place in the industry's agenda. It could safely be stated that industry has pursued the goal of awareness and education to an extent that can reasonably be expected. Although there will always be room for relevant fora to exchange ideas and foster feedback, it is time to progress beyond the stage of just talking and exchanging exciting stories. One way to accomplish this progression is to ensure that important developments emanating from workshops, seminars, etc., be made available, accepted and implemented at the world-wide level. To accomplish this goal, it is imperative to establish and introduce a requirement to include human factors knowledge into the certification process of equipment, procedures and personnel through legislation that is binding to the larger community. Should such a development take place, there would be a measure of assurance that, by virtue of the imperatives of regulation, a macro-approach to high-technology systems design will replace existing micro-approaches.

Having been developed by the International Civil Aviation Organization (ICAO), the crux of this paper is toward the understanding, acceptance and importance of standards and practices relevant to the certification processes which would be implementable at the world-wide level. It is therefore important to discuss the role and processes of ICAO toward the attainment of these goals for the purpose of clarifying the virtues of international standardization and cooperation which points the way toward a wider level of implementation and acceptance of the important work currently being developed concerning human factors certification of advanced systems. For certification in aviation to have significant relevance, it is imperative that it have world-wide application and standardization. Considering the global aspect of the CNS/ATM System, which will be based on satellite technology, the need to efficiently integrate all of the elements of the system on a wide level can be seen. Whether we are discussing air traffic control procedures, pilot licensing, aviation training or maintenance procedures, it is essential that there be international agreement between nations for regulations to be effective, worthwhile and able to achieve all potentialities. Consider the following example: in an afternoon's flight, an airliner can cross the territories of several nations; nations in which different languages are spoken and in which different legal codes are used. In all of these operations, safety must be paramount; there must be no possibility of unfamiliarity or misunderstanding. In other words, there must be international standardization and agreement between nations in all technical, economic and legal fields. To accomplish these difficult goals, the nations of the world established ICAO to serve as the medium through which this necessary international understanding and agreement can be reached. It acts as the mechanism whereby global coordination and harmonization is achieved.

The main accomplishments of ICAO associated with regulation, and thereby certification, have been the agreement of its Member States on the necessary standardization for the operation of safe, efficient and regular air services. This standardization has been achieved primarily through the adoption by the ICAO Council, as Annexes to the Chicago Convention, of specifications known as International Standards and Recommended Practices. The 18 Annexes so far adopted cover the whole spectrum of aviation. A Standard is any specification for physical characteristic, configuration, materiel, performance, personnel or procedure, the uniform application of which is recognized as necessary for the safety or regularity of international air navigation and to which contracting states will conform in accordance with the Convention. In the event of impossibility of compliance, notification to the ICAO Council is compulsory. A Recommended Practice is any specification for physical characteristic, configuration, materiel, performance, personnel or procedure, the uniform application of which is recognized as desirable in the interests of safety, regularity or efficiency of international air navigation, and to which contracting States will endeavour to conform in accordance with the Convention (ICAO, 1990).

An Overview of the ICAO Annexes

This overview is developed so that an understanding of the Annexes and their application toward the development of certification standards for human factors may be achieved. The Annexes to the Convention on International Civil Aviation have reduced many of the complexities of air transportation to everyday routine. They govern the standards of performance required of pilots and air traffic controllers. The ICAO licensing requirements must be met by all contracting States and they apply not only to pilots, flight crews and controllers, but also to ground maintenance crews. International specifications also exist for the

design and performance of aircraft themselves and the equipment aboard. The rules of the air, by which pilots fly, were formulated by ICAO. These include both visual flight rules and instrument flight rules. The weather reports, so vital to the safety of international travel, are provided to pilots and airport staff by a world-wide network of meteorological stations. The aeronautical charts used for navigation throughout the world are also specified by ICAO, and all the symbols and terms on these charts are standardized for uniformity so that no confusion can ever arise. Even units of measurement used in aircraft communications are standardized so that no pilot can be confused when he/she is given a distance by a ground-based air traffic controller. Aircraft telecommunications systems, radio frequencies and procedures are also ICAO's responsibility. The way in which aircraft are operated is regulated by ICAO so that an international level of safety is maintained. Uniform rules of airworthiness of aircraft are ensured by internationally agreed certification processes. Without that certification, no aircraft can be accepted for flight. Even the requirements for aircraft registration and their identifying marks are based on international standards. ICAO also gives continued attention to ways and means of ensuring better utilization of airspace in high traffic density areas and providing for greater air traffic handling capacity. Measures to regulate the flow of air traffic along heavily traveled air routes are being applied and refined to reduce or eliminate excessive delays in flight. To facilitate free and unimpeded passage of aircraft and their loads, ICAO seeks to speed up customs, immigration, public health and other procedures for passengers, crews, baggage, cargo and mail across international boundaries and to ensure that essential facilities and services are provided at international airports. ICAO has made significant progress in reducing aircraft noise by adopting stringent noise limitations for aircraft engines. This continuing effort has already resulted in a whole new generation of quieter aircraft. Safeguarding international civil aviation against unlawful seizure of aircraft, sabotage and bomb threats has received special consideration during recent years. The standards, recommended practices and guidance material on airport security have resulted in a marked decrease of such incidents. Finally, ICAO has recently introduced a comprehensive set of recommendations for the safe transport of dangerous goods to be applied uniformly all over the world. This latest Annex shows how remarkably well the Chicago Convention meets the continuing standardization needs, which are so intrinsically tied to certification, of civil aviation (ICAO, 1982). A list of the currently existing Annexes is at Attachment B.

The ICAO Global CNS/ATM System

A discussion about the ICAO CNS/ATM global system is necessary as it can be identified as a major and complex set of new systems that will be the major influence on all new systems developed for civil aviation. An opportunity exists for an early human factors input which should include human factors certification possibilities. The human factors profession should seek to ensure that all involved with the development and implementation of the CNS/ATM system are made aware of the possibilities regarding human factors certification along with the traditional human factors involvement. Human factors awareness should be sought after by all involved, especially those involved in international civil aviation and the development of international regulations.

The ICAO Global CNS/ATM concept was developed by the ICAO Future Air Navigation Services (FANS) Special Committee which was established by the ICAO Council at the end of 1983 to study, identify and assess new concepts and new technology in the field of air navigation (including satellite technology) and to make recommendations for the development

of air navigation for international civil aviation over the period of the next twenty-five years. The Tenth Air Navigation Conference, held in Montreal in September, 1991, endorsed the findings of the FANS Committee which identified the major elements of the planned future system. These elements are Communications, Navigation and Surveillance which will be increasingly accomplished through the use of satellite technology. A resulting Air Traffic Management System would have the capability of resolving the shortcomings of the present air navigation system and of alleviating some of the air traffic congestion problems experienced in many parts of the world. The implications for human factors certification of advanced systems is evident and offers a further direction of study and discussion for future gatherings (ICAO, 1991).

The Tenth Air Navigation Conference endorsed the view that the planning and implementation of improved Air Traffic Management capabilities should include considerations of human factors impacts and requirements. They further stated that the many goals listed for the future Air Traffic Management System should be qualified in relation to human factors. The Tenth Air Navigation Conference recommended that work by ICAO in the field of human factors include studies related to the use and transition to the future CNS/ATM System and that ICAO encourage member States to undertake such studies. It also developed a list of considerations which are recommended for use when determining human factors aspects in relation to the CNS/ATM system. These are listed in Attachment A for discussion purposes. It is certain that human factors will be considered in all phases of implementation of the new systems. It is important to consider ways in which human factors certification can be introduced into this important development.

Discussion of Human Factors and the Certification Process

Consider what has recently been achieved concerning Personnel Licensing. In the last revision to Annex I, a requirement has been included to the effect that each applicant for a license must demonstrate appropriate knowledge regarding: "human performance and limitations relevant to.(the license being issued)" (ICAO, 1988). Annex I also includes an augmented requirement for the demonstration of certain skills in a manner which dictates increased attention to particular aspects of human performance. Thus, for example, the holder of an Airplane Transport Pilot License "shall demonstrate the ability to: exercise good judgment and airmanship, understand and apply crew coordination and incapacitation procedures; and, communicate effectively with other flight crew members."

This requirement effectively guarantees that, during the certification process (i.e., licensing and training) of operational personnel, human factors considerations must be duly accounted in the form of demonstration of human factors knowledge and skills. Other isolated efforts exist in the certification of procedures (Wiener, 1990). These efforts are valuable but are, nevertheless, random efforts toward pursuing an avenue of action which deserves serious consideration and the necessary framework for institutionalization which only regulation – international regulation – can assure. The initiative here should belong with the international community, and it is further contended that it should be pursued as such and within the context of existing structures.

From the perspective of ICAO, the inclusion of human factors requirements, following the licensing process of operational personnel as outlined in Annex I (example above) is viewed as one possible way to proceed. The Annexes are well established and internationally accepted documents covering all aspects of aviation and as such, provide an ideal structure. ICAO contracting States must observe and abide by their provisions if these States are to be accepted as members of the international community. It is difficult to identify a more solid foundation upon which to build the much needed framework necessary for legislating human factors. The ICAO Annexes are subjected to periodic revisions to ensure the relevance and applicability of their contents. It is suggested that each of these Annexes might be analyzed by dedicated groups of experts who would endeavour to pinpoint if and where the inclusion of human factors requirements in such documents would be appropriate. Should it be deemed feasible, the drafted requirements would eventually be included in the Annexes as they progress through their routine revision cycles. At this level of analysis and drafting, the requirements would be broad in nature and scope. Annex I stands as a leading example to follow.

Once the basic requirements are legislated, even in the broadest terms, the responsibility will by force switch to the international research, design and training communities who would then have to find the means and tools to implement such requirements into practice. And while the ICAO Annexes would establish the policies, the international community would devise the appropriate procedures to achieve such policies. This combination has worked quite satisfactorily and has produced consistent and successful results throughout the implementation of Annex I (i.e., certification of personnel).

Questions for Discussion

In addressing the questions put forward by the organizers of this workshop, some early and tentative answers can be advanced. They are simple and general and need refinement. It is felt, however, that often times simple realities must be reasserted to further progress. Secondly, they are viewed as a bridge to foster sound discussion and an open exchange of information. Thirdly, they are submitted as a preliminary attempt to provide a foundation to help orient discussion of a subject that appears, at first, abstract and controversial and upon which professional and cultural biases and preferences may have influence. Short answers to the questions upon which discussion during the workshop revolve are proposed hereunder.

Who should have the authority to perform the human factors certification process when considering advanced aviation systems? Certification should remain a responsibility of the national authorities. It is suggested, however, that the certification process could be facilitated if placed under the general umbrella of "ICAO human factors Requirements," and internationally accepted. Such requirements would provide a basic framework and would be established with the support of the appropriate sectors of the international community. The approval process (even if only an endorsement) by ICAO would enhance the credibility of the requirements at the world-wide level.

Where/How should certification be accomplished? Within the general guidelines as discussed in the answers developed in this paper. The review of the ICAO Annexes and the subsequent inclusion of human factors certification requirements by groups of experts from

different States, called upon by ICAO, would allow national authorities to include the human factors certification requirements during the normal certification processes dealing with the "hard" components of an advanced system.

What should be certified? This question can be appropriately addressed only after the ICAO Annexes are reviewed by groups of experts and the relevant human factors requirements are incorporated into them.

Why should it be certified? The arguments advanced in the background discussion of this paper and at this workshop as a whole are considered as the justification and answer to this question.

Conclusion

It is appropriate here to repeat the analogy described in the introduction to this paper which is: That the consideration of human factors requirements during the design stage of advanced, new technology systems may be seen as resting over a three-legged stool. The first leg, the equipment that a system will utilise to achieve its goals, has traditionally attracted ergonomic considerations associated with equipment design, usually centred around "knobs and dials." Lately, this view has expanded to include the so-called other important aspect of Human Factor's study which deals with the cognitive, behaviourial and social processes of the human operators. Study in this area must be furthered. The second leg of the stool, the procedures to operate the equipment, however, has been largely unaddressed. Procedures are not inherent to equipment, but must be developed. The importance of proper human factors consideration in the design of procedures can not be overstated. Lastly, the third leg of the stool, the certification of personnel who will operate the equipment, is very much underway, but far from being complete. The real quest now, however, is to integrate these three legs into an indivisible one.

Finally, and most importantly, this workshop and its topic are extremely timely in that we are at the dawn of the most ambitious development ever undertaken in international civil aviation. This would allow us the rather unique opportunity to put theory into practice in the near future by ensuring that the concepts developed and furthered by this workshop and the follow-up are implemented in the design and certification of the ICAO future CNS/ATM systems described earlier in this paper. Now is the time to incorporate human factors requirements during the certification processes of these systems. This might act as a test to the feasibility of these ideas. Such endeavors represent a challenge for the research, engineering, training, operational and regulatory communities. But there is certainly more to be gained by attempting to meet the challenge rather than refraining from progress by decrying the difficulties involved.

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APPENDIX A

LIST OF CONSIDERATIONS WHICH ARE RECOMMENDED TO BE USED WHEN DETERMINING HUMAN FACTOR'S ASPECTS IN RELATION TO THE CNS/ATM SYSTEM

a) The level of safety targeted for the future system should be defined not only with reference to various system statistics, but also with reference to error-inducing mechanisms such as human capabilities and limitations as well as important individual cases.

b) Definition of system and resource capacity should include reference to the responsibilities, capabilities and limitations of ATS personnel and air crews who must retain situation awareness and understanding in order to carry out all of their responsibilities.

c) Dynamic accommodation of three and four-dimensional flight trajectories to provide user-preferred routings while an ultimate goal for users may initially be restricted by human capabilities and the need to organize the flow of air traffic in an orderly manner in order to provide separation. The transition period will need careful research and evaluation on human factors aspects.

d) Provision of large volumes of potentially relevant information to users and ATS personnel should be limited to what is absolutely necessary and mediated by methods that effectively package and manage such information to prevent information overload while providing information pertinent to particular operational needs.

e) Human computer dialogues serving flight "air and ground requests" should be consistent in form and style with the ways in which air crews and controllers plan and negotiate.

f) A single airspace continuum should be free of operational discontinuities and inconsistencies between kinds of airspace and kinds of facilities that affect responsibilities and activities of air crews or ATS personnel at functional boundaries.

g) Organization of airspace in accordance with ATM procedures should also be readily learnable, recallable, and, to the maximum practical extent, intuitively understandable by air crews and ATS personnel.

h) Responsibilities of pilots, air traffic controllers and system designers should be clearly designed prior to the implementation of new automated systems and tools (e.g., conflict resolution advisories, data link, ADS, etc.).

In addition to the analysis and assessment aimed at the specific concerns just outlined, evolution of the ATM should be accompanied by systematic pre- and post-implementation evaluations of its more general human factors impacts. These assessments should encompass its effects on aircrew and ATS personnel workload and performance, as well as implications for their selection, training, career progression and health.

APPENDIX B

DESCRIPTION OF ICAO ANNEXES

ANNEX

1) Personnel Licensing
2) Rules of the Air
3) Meteorological Service for International Air Navigation
4) Aeronautical Charts
5) Units of Measurement to be used in Air and Ground Operations
6) Operation of Aircraft
   - Part I – International Commercial Air Transport-Aeroplanes
   - Part II – International General Aviation-Aeroplanes
   - Part III – International Operations-Helicopters
7) Aircraft Nationality and Registration Marks
8) Airworthiness of Aircraft
9) Facilitation
10) Aeronautical Telecommunications
11) Air Traffic Services
12) Search and Rescue
13) Aircraft Accident Investigation
14) Aerodromes
15) Aeronautical Information Services
16) Environmental Protection
17) Security
18) The Safe Transport of Dangerous Goods by Air